TITLE OF THE INVENTION

CRYSTALLIZATION APPARATUS, CRYSTALLIZATION METHOD,

PHASE MODULATION ELEMENT, DEVICE AND DISPLAY APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the
benefit of priority from prior Japanese Patent
Application No. 2003-117486, filed April 22, 2003, the
entire contents of which are incorporated herein by
reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a crystallization
apparatus, a crystallization method, a phase modulation
element, a device and a display apparatus used to
generate a crystallized semiconductor film by
irradiating a polycrystal semiconductor film or
an amorphous semiconductor film with laser beams having
a predetermined light intensity.

2. Description of the Related Art

For example, a thin film transistor (TFT) used
for, e.g., a switching element which controls a voltage
applied to pixels in a liquid crystal display (LCD) is
formed on an amorphous silicon layer or a polysilicon
layer.

The polysilicon layer has a higher mobility of
electrons or electron holes than that of the amorphous
silicon layer. Therefore, when a transistor is formed

on the polysilicon layer, a switching speed is
increased and a response speed of a display is improved
as compared with a case that a transistor is formed on
the amorphous silicon layer.

5   Further, a peripheral LSI can be constituted of
a thin film transistor. Furthermore, there is
an advantage that a design margin of any other
component can be reduced. Moreover, when peripheral
circuits such as a driver circuit or a DAC are

10   incorporated in a display, these peripheral circuits
can be operated at a higher speed.

Although the polycrystal silicon is formed of
an aggregation of crystal grains, it has a lower
mobility of electrons or electron holes than that of

15   single crystal silicon. Additionally, many thin film
transistors formed on the polycrystal silicon have
a problem of irregularities in crystal grain boundary
number in a channel portion. Thus, in order to improve
the mobility of electrons or electron holes and

20   reduce irregularities in crystal grain boundary number
in the channel portion, there has been proposed
a crystallization method which generates crystallized
silicon with a large grain size.

As this type of crystallization method, there is

25   known a "phase control ELA (Excimer Laser Annealing)
method) which generates a crystallized semiconductor
film by irradiating a phase shifter approximated to

a polycrystal semiconductor film or an amorphous
semiconductor film in parallel with excimer laser
beams. The detail of the phase control ELA method is
disclosed in, e.g., "Surface Science Vol. 21, No. 5,
5   pp. 278-287, 2000".

In the phase control ELA method, a light intensity
distribution with an inverse peak pattern (pattern that
a light intensity is substantially zero at the center
and the light intensity is suddenly increased toward
10   the periphery) that a light intensity is substantially
zero at a point corresponding to a phase shift portion
of a phase shifter is generated, and a polycrystal
semiconductor film or an amorphous semiconductor film
is irradiated with light beams having this light
15   intensity distribution with the inverse peak pattern.
As a result, a temperature gradient is generated in
a fusion area in accordance with the light intensity
distribution, a crystal nucleus is formed at a part
which is solidified first in accordance with a point
20   where the light intensity is substantially zero, and
a crystal grows in the lateral direction from
the crystal nucleus toward the periphery (which will be
referred to as a "lateral growth" or a "lateral-
directional growth" hereinafter), thereby producing
25   single crystal grains with a large particle size.

Additionally, Jpn. Pat. Appln. KOKAI Publication
No. 2000-306859 discloses a technique to perform

crystallization by irradiating a semiconductor film
with light beams having a light intensity distribution
with an inverse peak pattern generated through a phase
shift mask (phase shifter).

Further, "Amplitude of Silicon Thin Film/Phase
Control Excimer Laser Fusion Recrystallization Method -
New 2-D Position-controlled Large Crystal Grain Forming
Method-", Inoue, Nakata and Matsumura, The institute of
Electronics, Information and Communication Engineers
Transactions Vol. J85-C, No. 8, pp. 624-629, Aug. 2002
discloses a technique to perform crystallization by
irradiating a semiconductor film with light beams
having a light intensity including a concave pattern
and an inverse pattern generated by combining a phase
shifter and a light absorption distribution (see FIG. 3
and a relevant description).

As disclosed in Jpn. Pat. Appln. KOKAI Publication
No. 2000-306859, according to the technique to form
a light intensity distribution with an inverse peak
pattern by using a phase shifter, the light intensity
distribution with the inverse peak pattern is formed at
a part corresponding to a phase shift portion.
However, since the light intensity is not linearly
increased and an additional irregular distribution is
generated around the light intensity distribution with
the inverse peak pattern, the growth of the crystal is
apt to be finished halfway.

It is to be noted that the obtained light intensity distribution may be possibly caused to approximate an ideal distribution by adjusting an angle distribution of illumination light beams relative to the phase shifter or designing an arrangement position of the phase shifter. However, that design cannot be analytically performed with a perspective, and it can be expected that very complicated design conditions are given even if the analytic design can be realized.

On the other hand, as disclosed in The institute of Electronics, Information and Communication Engineers Transactions, according to the technique in which the phase shifter is combined with the light absorption distribution, a light intensity distribution with the concave pattern and the inverse peak pattern for crystallization can be obtained. However, it is difficult to realize this distribution. That is, forming a film having a light absorption distribution which continuously varies is generally difficult. Further, light beams having a very strong intensity for crystallization is undesirable since it tends to generate a deterioration in a film material of a film having a light absorption distribution due to heat from light absorption or a chemical change when a film to be crystallized is irradiated.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to

provide a crystallization apparatus which can generate a crystallized semiconductor film with a large grain size by causing a crystal to grow in the lateral direction from a crystal nucleus, a crystallization method, a thin film transistor using a crystallized semiconductor film and a display apparatus.

According to an aspect of the present invention, there is provided a crystallization apparatus comprising: a phase modulation element in which a phase of outgoing light beams relative to incident light beams differs depending on each position; an illumination system used to generate the incident light beams which enter the phase modulation element; an image formation optical system provided on an outgoing radiation side of the phase modulation element; and a stage used to support a substrate having a non-single crystal semiconductor film provided on an outgoing radiation side of the image formation optical system, wherein the phase modulation element has a phase distribution based on a phase modulation unit which is optically smaller than a radius of a point spread distribution range of the image formation optical system when converted to an image formation surface of the image formation optical system.

According to another aspect of the present invention, there is provided an exposure apparatus comprising: a phase modulation element in which a phase

of outgoing light beams relative to incident light beams differs depending on each position; an illumination system used to generate the incident light beams which enter the phase modulation element; an image formation optical system provided on an outgoing radiation side of the phase modulation element; and an image formation optical system arranged in a light path between the phase modulation element and a predetermined surface, wherein the phase modulation element has a phase distribution based on a phase modulation unit which is optically smaller than a radius of a point spread distribution range of the image formation optical system when converted to an image formation surface of the image formation optical system.

According to still another aspect of the present invention, there is provided a crystallization method comprising: illuminating a phase modulation element having a phase distribution based on a phase modulation unit which is optically smaller than a radius of a point spread distribution range of an image formation optical system when converted to an image formation surface; and irradiating a polycrystal semiconductor film or an amorphous semiconductor film with light beams having a predetermined light intensity distribution through the image formation optical system arranged in a light path between the phase modulation

element and the polycrystal semiconductor film or the
amorphous semiconductor film, thereby generating a
crystallized semiconductor film.

According to a further aspect of the present
5   invention, there is provided a crystallization method
comprising: illuminating a phase modulation element
having a phase distribution based on a phase modulation
unit which is optically smaller than a radius of
a point spread distribution range of an image formation
10   optical system when converted to an image formation
surface; and forming a predetermined light intensity
distribution on a predetermined surface through the
image formation optical system arranged in a light path
between the phase modulation element and the
15   predetermined surface.

According to a still further aspect of the present
invention, there is provided a phase modulation element
having a phase distribution based on a phase modulation
unit having a predetermined size, comprising: a first
20   area having a first phase value; and a second area
having a second phase value, wherein the phase
distribution is defined by a change in area shares of
the first area and the second area depending on each
position.

25   According to a still further aspect of the present
invention, there is provided a phase modulation element
having a phase distribution based on a phase modulation

unit having a predetermined size, comprising:

a plurality of divided areas each having a fixed phase

value, wherein each of the divided areas has a phase

distribution that the phase value cyclically varies in

5 accordance with each divided area.

According to a still further aspect of the present

invention, there is provided a phase modulation element

having a phase distribution based on a phase modulation

unit having a predetermined size, comprising: a first

10 stripe-like area which has a first phase distribution

and extends in a direction along which a phase varies;

and a second stripe-like area which has a second phase

distribution and extends in the direction along which

the phase varies, wherein the first stripe-like area

15 and the second stripe-like area are adjacent to each

other with a border line parallel with the direction

along which the phase varies therebetween, and

an average phase value on the first stripe-like area

side is substantially different from an average phase

20 value on the second stripe-like area side in a local

area on the border line.

According to a still further aspect of the present

invention, there is provided a device comprising:

a semiconductor film manufactured by a crystallization

25 method, the crystallization method comprising:

illuminating a phase modulation element having a phase

distribution based on a phase modulation unit which is

optically smaller than a radius of a point spread
distribution range of an image formation optical system
when converted to an image formation surface; and
forming a predetermined light intensity distribution on

5   a predetermined surface through the image formation
optical system arranged in a light path between the
phase modulation element and the predetermined surface.

According to a still further aspect of the present
invention, there is provided a display apparatus

10   comprising: a pair of substrates joined to each other
with a predetermined gap therebetween; an electro-optic
material held in the gap; an opposed electrode formed
on one of the substrates; and a semiconductor thin film
which can provide pixel electrodes formed on the other

15   substrate and thin film transistors which drive the
pixel electrodes, wherein the semiconductor thin film
is a semiconductor film crystallized by irradiating
the polycrystal semiconductor film or the amorphous
semiconductor film with light beams having

20   a predetermined light intensity distribution through
a phase modulation element in which a phase of outgoing
light beams relative to incident light beams varies
depending on each position and an image formation
optical system.

25   Additional objects and advantages of the invention
will be set forth in the description which follows, and
in part will be obvious from the description, or may be

learned by practice of the invention. The objects and
advantages of the invention may be realized and
obtained by means of the instrumentalities and
combinations particularly pointed out hereinafter.

5   BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated
in and constitute a part of the specification,
illustrate embodiments of the invention, and together
with the general description given above and the

10   detailed description of the embodiments given below,
serve to explain the principles of the invention.

FIG. 1 is a schematic view illustrating an example
of a structure of a crystallization apparatus according
to an embodiment of the present invention;

15   FIG. 2 is a schematic view illustrating an example
of an internal structure of an illumination system
depicted in FIG. 1;

FIGS. 3A to 3F are schematic views illustrating
a basic principle of the present invention;

20   FIGS. 4A to 4C are schematic views illustrating
a relationship between changes in phase and a light
intensity in a point spread distribution range;

FIGS. 5A and 5B are schematic views illustrating
a relationship between a pupil function and a point

25   spread function in an image formation optical system;

FIG. 6A is a schematic view illustrating
an example of an embodiment of a phase modulation

element;

FIG. 6B is a schematic view illustrating an example of changes in area shares of each cell of the phase modulation element depicted in FIG. 6A;

5   FIG. 7 is a schematic view illustrating another embodiment of the phase modulation element according to the present invention;

FIG. 8 is a schematic view illustrating still another embodiment of the phase modulation element

10   according to the present invention;

FIG. 9A is a schematic view illustrating yet another embodiment of the phase modulation element according to the present invention;

FIG. 9B is a schematic view showing a light

15   intensity distribution provided by the phase modulation element depicted in FIG. 9A;

FIG. 9C is a schematic view illustrating an example that the phase modulation element depicted in FIG. 9A is also arranged in a direction indicated by

20   an arrow y orthogonal to a direction indicated by an arrow x;

FIG. 9D is a schematic view showing a light intensity distribution provided by the phase modulation element illustrated in FIG. 9C;

25   FIG. 10A is a schematic view illustrating a further embodiment of the phase modulation element according to the present invention;

FIG. 10B is a schematic view showing a light intensity distribution provided by the phase modulation element depicted in FIG. 10A;

FIG. 11A is a schematic view illustrating a still further embodiment of the phase modulation element according to the present invention;

FIG. 11B is a schematic view showing a light intensity distribution provided by the phase modulation element depicted in FIG. 11A;

FIG. 12A is a schematic view illustrating a yet further embodiment of the phase modulation element according to the present invention;

FIG. 12B is a schematic view showing a light intensity distribution along a line A-A in FIG. 12A;

FIG. 12C is a schematic view showing a light intensity distribution along a border line B-B in FIG. 12A;

FIG. 13 is a schematic view illustrating characteristics of the phase modulation element depicted in FIGS. 12A to 12C;

FIG. 14A is a schematic view illustrating another embodiment of the phase modulation element according to the present invention;

FIG. 14B is a schematic view illustrating a modification of the phase modulation element depicted in FIG. 14A;

FIG. 15A is a schematic view showing in a contour

map a light intensity distribution obtained in the
phase modulation element depicted in FIG. 14A;

FIG. 15B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 15A;

FIG. 15C is a schematic view showing a light
intensity distribution along the border line B-B in
FIG. 15A;

FIG. 16A is a schematic view illustrating still
another embodiment of the phase modulation element
according to the present invention;

FIG. 16B is a schematic view illustrating
a modification of the phase modulation element depicted
in FIG. 16A;

FIG. 17A is a schematic view showing in a contour
map a light intensity distribution obtained in
the phase modulation element depicted in FIG. 16A;

FIG. 17B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 17A;

FIG. 17C is a schematic view showing a light
intensity distribution along the border line B-B in
FIG. 17A;

FIG. 18A is a schematic view illustrating yet
another embodiment of the phase modulation element
according to the present invention;

FIG. 18B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 18A;

FIG. 18C is a schematic view showing a light

intensity distribution along the border line B-B in
FIG. 18A;

FIG. 19A is a schematic view illustrating
a further embodiment of the phase modulation element
according to the present invention;

FIG. 19B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 19A;

FIG. 19C is a schematic view showing a light
intensity distribution along the border line B-B in
FIG. 19A;

FIG. 20A is a schematic view showing in a contour
map a light intensity distribution obtained in the
phase modulation element depicted in FIG. 19A;

FIG. 20B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 20A;

FIG. 20C is a schematic view showing a light
intensity distribution along the border line B-B in
FIG. 20A;

FIG. 21A is a schematic view illustrating a still
further embodiment of the phase modulation element
according to the present invention;

FIG. 21B is a schematic view showing a light
intensity distribution along the line A-A in FIG. 21A;

FIG. 21C is a schematic view showing a light
intensity distribution along the border line B-B in
FIG. 21A;

FIG. 22A is a schematic view illustrating a yet

further embodiment of the phase modulation element according to the present invention;

FIG. 22B is a schematic view showing a light intensity distribution along the line A-A in FIG. 22A;

FIG. 22C is a schematic view showing a light intensity distribution along the border line B-B in FIG. 22A;

FIG. 23A is a schematic view illustrating another embodiment of the phase modulation element according to the present invention;

FIG. 23B is a schematic view showing a light intensity distribution along the line A-A in FIG. 23A;

FIG. 23C is a schematic view showing a light intensity distribution along the border line B-B in FIG. 23A;

FIG. 24A is a schematic view illustrating still another embodiment of the phase modulation element according to the present invention;

FIG. 24B is a schematic view showing a light intensity distribution along the line A-A in FIG. 24A;

FIG. 24C is a schematic view showing a light intensity distribution along the border line B-B in FIG. 24A;

FIG. 25A is a schematic view illustrating yet another embodiment of the phase modulation element according to the present invention;

FIG. 25B is a schematic view showing a light

intensity distribution along the lien A-A in FIG. 25A;

FIG. 25C is a schematic view showing a light intensity distribution along the line the border line B-B in FIG. 25A;

FIGS. 26A to 26E are schematic view illustrating an example of a process to manufacture an electronic device on a transparent substrate obtained by a crystallization apparatus according to the present invention;

FIG. 27 is a schematic view illustrating an example to apply a transparent substrate obtained by the crystallization apparatus according to the present invention to a display apparatus, e.g., an active matrix type liquid crystal display; and

FIG. 28 is a schematic view illustrating an example to apply a transparent substrate obtained by the crystallization apparatus according to the present invention to a display apparatus, e.g., an active matrix type liquid crystal display.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments according to the present invention will now be described hereinafter with reference to the accompanying drawings.

FIG. 1 is a view schematically showing a structure of a crystallization apparatus according to an embodiment of the present invention. Further, FIG. 2 is a view schematically showing an internal structure

of an illumination system of FIG. 1. Referring to
FIGS. 1 and 2, a crystallization apparatus according to
this embodiment comprises an illumination system 2
used to illuminate a phase modulation element 1.

5   A structure and an effect of the phase modulation
element 1 will be described later.

The illumination system 2 comprises a laser beam
source which generates incident light beams which enter
the phase modulation element 1, e.g., a KrF excimer

10   laser beam source 2a which supplies light beams having
a wavelength of 248 nm used to crystallize a non-single
crystal semiconductor film such as an amorphous silicon
film or a polycrystal silicon film. It is to be noted
that any other appropriate beam source such as an XeCl

15   excimer laser beam source or a YAG laser beam source
can be also used as the beam source 2a.

Laser beams supplied from the beam source 2a are
expanded through a beam expander 2b and then enter
a first fly-eye lens 2c.

20   A plurality of pseudo-beam sources are formed on
a rear focal plane of the first fly-eye lens 2c
(an image of the beam source 2a is transferred to
the rear focal plane of the first fly-eye lens 2c and
pseudo-beam sources are defined). Light fluxes from

25   the rear focal plane of the first fly-eye lens 2c,
i.e., the plurality of (pseudo-) beam sources are led
to an incident plane of a second fly-eye lens 2e

through a first condenser optical system 2d. As a result, more pseudo-beam sources than those on the rear focal plane of the first fly-eye lens 2c are formed on a rear focal plane of the second fly-eye lens 2e

5   (an image of the first fly-eye lens 2c is transferred on the rear focal plane of the second fly-eye lens 2e and pseudo-beam sources are defined). Light fluxes from the plurality of beam sources formed on the rear focal plane of second fly eye lens 2e are caused to

10   enter the phase modulation element 1 through a second condenser optical system 2f.

     The first fly-eye lens 2c and the first condenser optical system 2d constitute a first homogenizer (i.e., a homogenization mechanism) which gives homogenization

15   (effect) to illumination beams from the beam source 2a. Therefore, the laser beams supplied from the beam source 2a are caused to enter the second fly-eye lens 2e in a state that an in-plane intensity distribution is homogenized by this first homogenizer.

20   Furthermore, the second fly-eye lens 2e and the second condenser optical system 2f constitute a second homogenizer, and the phase modulation element 1 is irradiated with laser beams whose incident angle is homogenized by the first homogenizer in a state that

25   the in-plane intensity distribution is substantially homogeneous. In this manner, an entire area of the phase modulation element 1 is irradiated with the laser

beams having the homogenous incident angle distribution
and the homogenous in-plane intensity distribution by
the first fly-eye lens 2c, the first condenser optical
system 2d, the second fly-eye lens 2e and the second
5   condenser optical system 2f.

The laser beams phase-modulated by the phase
modulation element 1 are caused to enter a processed
substrate 4 provided on an outgoing radiation side of
an image formation optical system 3.

10   The image formation optical system 3 comprises
a convex lens 3a, a convex lens 3b and an aperture
diaphragm 3c provided between the both lenses, and can
position the phase modulation element 1 and the
processed substrate 4 in an optically conjugate
15   positional relationship.

In other words, the processed substrate 4 has a
film which is subjected to crystallization processing,
and is set on a surface optically conjugate with the
phase modulation element 1 (image surface of the image
20   formation optical system 3). It is to be noted that
the processed substrate 4 is positioned and held at a
predetermined position on a substrate stage 5 by using
a vacuum chuck, an electrostatic chuck or the like.

The aperture diaphragm 3c can arbitrary set a size
25   of an aperture (light transmission portion). It is to
be noted that the aperture diaphragm 3c can be
arbitrarily selected from, e.g., an iris diaphragm

which can continuously change a size of the aperture. Moreover, a plurality of plate-like bodies each of which has an aperture with a predetermined size provided thereto may be prepared and arbitrarily set in a light path. In any case, the size of the aperture of the aperture diaphragm 3c (which is substantially an image side numerical aperture NA of the image formation optical system 3) is set so as to generate a necessary light intensity distribution on a semiconductor film of the processed substrate 4 as will be described later.

It is to be noted that the image formation optical system 3 may be a refraction type optical system, a reflection type optical system or a refraction/reflection type optical system. Additionally, the processed substrate 4 is obtained by sequentially forming an underlying film (lower layer protection film) and a non-single crystal semiconductor film such as an amorphous silicon film on, e.g., a liquid crystal display glass sheet by chemical vapor deposition (CVD).

FIGS. 3A to 3F are views illustrating a basic principle of the present invention. Like reference numerals denote parts equal to those in FIGS. 1 and 2, thereby eliminating their detailed explanation.

Generally, a light amplitude distribution U (x, y) of image formation by the phase modulation element 1 is represented by the following expression (1):

$$U(x, y) = T(x, y) * ASF(x, y) \qquad \ldots(1)$$

It is to be noted that $T(x, y)$ indicates a complex amplitude transmittance distribution of the phase modulation element 1; *, a convolution (convolution integral); an $ASF(x, y)$, a point spread function of the image formation optical system 3. Furthermore, the point spread function is defined as an amplitude distribution of a point image obtained by the image formation optical system.

It is to be noted that the complex amplitude transmittance distribution T of the phase modulation element 1 is represented by the following expression (2) since it has a homogenous amplitude;

$$T = T_0 e^{i\phi(x, y)} \qquad \ldots(2)$$

It is to be noted that T_0 is a fixed value and $\phi(x, y)$ indicates a phase distribution in the expression (2).

Moreover, when the image formation optical system 3 has a homogenous circular pupil and no aberration, a relationship represented by the following expression (3) is achieved in connection with the point spread function $ASF(x, y)$:

$$ASF(x, y) \propto 2J_1(2\pi/\lambda \cdot NA \cdot r) / (2\pi/\lambda \cdot NA \cdot r) \qquad \ldots(3)$$

$$\text{where } r = (x^2 + y^2)^{1/2}$$

It is to be noted that J_1 indicates a Bessel function, λ indicates a wavelength of light beams and NA indicates an image side numeral aperture of the image formation optical system 3 as describe above in the

expression (3).

The point spread function of the image formation
optical system 3 depicted in FIG. 3A is a light
intensity distribution on an image surface 3f of

5   the processed substrate 4 and shown in FIG. 3B.
A horizontal axis shows an incident plane of the
processed substrate 4, and a vertical axis shows
an incident light intensity. The point spread function
of the image formation optical system 3 depicted in

10   FIG. 3A can be approximated by using a cylindrical
shape 3e having a diameter R indicated by a broken line
in FIG. 3B. That is, a result of integrating the
complex amplitude distribution in a circle having
a diameter R' (value optically corresponding to

15   the diameter R in FIG. 3B) on the phase modulation
element 1 depicted in FIG. 3C determines a complex
amplitude on the image surface 3f shown in FIG. 3A.

As described above, the light amplitude of image
formation image-formed on the image plane 3f, i.e., the

20   light intensity is given by the convolution between the
complex amplitude transmittance distribution of the
phase modulation element 1 and the point spread
function.

Giving a consideration by approximating the point

25   spread function by using the cylindrical shape 3e,
a result obtained by integrating the complex amplitude
transmittance of the phase modulation element 1 with

a homogenous weight in the circular point spread

distribution range shown in FIG. 3C becomes the complex

amplitude on the image surface 3f, and a square of its

absolute value becomes the light intensity. It is to

5   be noted that the point spread distribution range R in

the image formation optical system 3 means a range in

an intersection 3j of an amplitude curve and

a horizontal axis 3i in FIG. 3B plotted by using

the point spread function.

10   Therefore, the light intensity is increased as

a change in phase in the point spread distribution

range R is small. On the contrary, the light intensity

is decreased as a change in phase is large. This point

can be readily understood by considering a sum of phase

15   vectors 3h in a unit circle 3g as shown in FIG. 3D.

When the image surface 3f is an object, e.g.,

a semiconductor film, the point spread function of

FIG. 3B is a point spread function such as shown in

FIG. 3F. FIG. 3E is a view showing a point on the

20   image surface 3f, and a light intensity at this point

is determined by the above-described process.

FIGS. 4A to 4C are views showing a typical

relationship between changes in phase in the point

spread distribution range R and the light intensity.

25 · FIG. 4A is a view showing a case that phase values in

four areas are all zero degree, a sum of four phase

vectors 4g each having an amplitude of E in a direction

of zero degree is an amplitude 4E, and its square

corresponds to a light intensity 16I.

FIG. 4B is a view showing a case that phase values

of two areas are zero degree and phase values of the

5   other two areas are 90 degrees. In this case, a sum of

the two phase vectors in the direction of zero degree

and the two phase vectors in the direction of

90 degrees corresponds to an amplitude $2\sqrt{2}E$, and its

square corresponds to a light intensity 8I. FIG. 4C is

10   a view showing a case of an area having a phase value

of zero degree, an area having a phase value of

90 degrees, an area having a phase value of 180 degrees

and an area having a phase value of 270 degrees.

In this case, an amplitude of a sum of a phase vector

15   4s in the direction of zero degree, a phase vector 4t

in the direction of 90 degrees, a phase vector 4u in

the direction of 180 degrees and a phase vector 4v in

the direction of 270 degrees is 0E, and its square

corresponds to a light intensity 0I.

20   FIGS. 5A and 5B are views showing a relationship

between a pupil function and the point spread function

in the image formation optical system 3.

Generally, a point spread function (FIG. 5B) is

given by a Fourier transform of a pupil function

25   (FIG. 5A). Specifically, when the image formation

optical system 3 has a homogenous circular pupil and no

aberration, the point spread function ASF (x, y) is

presented by the above-described expression (3).
However, it is not restricted to the above if there is
an aberration in the image formation optical system 3
or the image formation optical system 3 has a pupil
function other than the homogenous circular pupil.

When the image formation optical system 3 has the
homogenous circular pupil and no aberration, it is
known that the a radius R/2 of a central area (i.e.,
an airy disk) until the point spread function becomes 0
first is represented by the following expression (4):

$$R/2 = 0.61\lambda/NA \qquad …(4)$$

In the present invention, the point spread
distribution range R means a circular central area
until the point spread function F(x) becomes zero first
as shown in FIGS. 3B and 5B. As apparent from FIGS. 4A
to 4C, when a circle optically corresponding to
the point spread distribution range R of the image
formation optical system includes a plurality of (four
in FIGS. 4A to 4C) phase modulation units, an amplitude
of the light beams, i.e., the light intensity can be
analytically controlled in accordance with a simple
calculation by using a sum of a plurality of phase
vectors 4g. As a result, a relatively complex light
intensity distribution can be comparatively readily
obtained.

Therefore, in the present invention, in order to
freely control the light intensity, the phase

modulation unit of the phase modulation element 1 must
be optically smaller than a radius of the point spread
distribution range R (see FIG. 3B) of the image
formation optical system 3, i.e., R/2. In other words,
a size of a phase distribution based on the phase
modulation unit of the phase modulation element 1 must
be smaller than the radius R/2 of the point spread
distribution range R of the image formation optical
system 3 when converted to the image formation surface
of the image formation optical system on the image side
of the image formation optical system 3. Here, in case
of a later-described cell type, the phase modulation
unit means a size of a shortest side of the cell. In
case of a pixel type, it means a length of one side.

A description will now be given as to an
embodiment of the phase modulation element 1 which can
be used in this embodiment.

FIG. 6A schematically shows a structure of the
phase modulation element 1, and FIG. 6B shows changes
in area shares of each cell of the phase modulation
element depicted in FIG. 6A.

Referring to FIG. 6A, the phase modulation
element 1 has a plurality of cells 21 which have sizes
optically smaller than the radius R/2 of the point
spread distribution range R of the image formation
optical system 3 and are indicated by a rectangular
wavy line. Further, each phase modulation element 1

has a first area 21a which is shaded and has a first phase value $\phi1$ and a second area 21b which is shown as a non-shaded space and has a second phase value $\phi2$.

As shown in FIG. 6A, area shares of the first area
5   21a having the phase value $\phi1$ (e.g., 90 degrees) and the second area 21b having the phase value $\phi2$ (e.g., zero degree) in each cell 21 vary in accordance with each cell. In other words, there is provided a phase distribution that the area shares of the first area 21a
10 having the phase value $\phi1$ and the second area 21b having the phase value $\phi2$ vary depending on each position. More specifically, an occupied area of the second area 21b having the phase value $\phi2$ in the cell is largest in the cell shown on the leftmost side, and
15 it is smallest in the cell shown on the rightmost side. It monotonously varies between these cells. Therefore, in the phase modulation element 1 formed of six cells depicted in FIG. 6, sizes of the areas having the different phase values continuously vary in each cell
20 as shown in FIG. 6B. The light beams to enter the phase modulation element 1 are transmitted from a front surface of a paper sheet (front side) in the direction of a rear surface of the same (inner side) as indicated by an arrow z.

25 As described above, the phase modulation element 1 has a phase distribution based on the phase modulation unit (cell) 21 having an optically smaller size than

the radius R/2 of the point spread distribution range R
of the image formation optical system 3. Therefore, by
appropriately changing the area shares of the first
area 21a and the second area 21b in each phase
5   modulation unit 21, i.e., a sum of the two phase
vectors, the light intensity distribution formed on the
processed substrate 4 (see FIG. 1) can be controlled by
using a predetermined calculation. The phase
modulation element 1 having the first and second phase
10   values $\phi1$ and $\phi2$ can be manufactured by selecting a
thickness of, e.g., a quarts glass so as to form the
first and second phase values $\phi1$ and $\phi2$. A change in
thickness of the quartz glass can be formed by
selective etching or an FIB (Focused Ion Beam).

15   FIG. 7 is a view schematically showing another
embodiment of the phase modulation element 1.

         Referring to FIG. 7, the phase modulation
element 1 has a plurality of rectangular pixels 22 each
of which is optically smaller than the radius R/2 of
20   the point spread distribution range R of the image
formation optical system 3. The plurality of pixels 22
are closely arranged in the both vertical and
horizontal directions, and each pixel 22 has a fixed
phase value. Specifically, the phase modulation
25   element 1 has shaded first pixels 22a each having
a first phase value $\phi1$ (e.g., 90 degrees) and
non-shaded second pixels each of which is shown as

a space and has a second phase value $\phi2$ (e.g., zero
degree). The incident light beams on the phase
modulation element 1 are transmitted from a front
surface of a paper sheet (front side) in a rear surface
5   direction (inner side) as indicated by an arrow z.

As shown in FIG. 7, the number of pixels having
the same phase value per unit range (indicated by
a circle C of a broken line) optically corresponding to
the point spread distribution range R (see FIG. 3B) of
10   the image formation optical system 3 is changed in
accordance with each unit range. In other words, the
phase modulation element 1 shown in FIG. 7 has a phase
distribution that the area shares of each first pixel
22a as a first area having the phase value $\phi1$ and each
15   second pixel 22b as a second area having the phase
value $\phi2$ vary depending on each position like the phase
modulation element shown in FIG. 6A.

As described above, the phase modulation element 1
shown in FIG. 7 has a phase distribution based on the
20   phase modulation unit (pixel) 22 having a size
optically smaller than the radius R/2 of the point
spread distribution range R of the image formation
optical system 3. Therefore, by appropriately changing
the area shares of the first pixels 22a and the second
25   pixels 22b in a unit range C in the phase modulation
element 1 optically corresponding to the point spread
distribution range R of the image formation optical

system 3, i.e., a sum of phase vectors, a light
intensity distribution formed on the processed
substrate 4 can be controlled by using a predetermined
calculation.

5   FIG. 8 is a view schematically showing still
another embodiment of the phase modulation element 1.
Referring to FIG. 8, the phase modulation element 1 has
a plurality of stripe-like areas 23 defined by
elongated triangle shapes each having an optically

10   smaller width than a radius of the unit range C
corresponding to the point spread distribution range R
of the image formation optical system 3. The plurality
of stripe-like areas 23 are closely arranged as shown
in the drawing, and each stripe-like area 23 has

15   a fixed phase value.

       Specifically, the phase modulation element 1 has
each shaded first stripe-like area 23a having a first
phase value $\phi 1$ (e.g., 90 degrees) and each non-shaded
second stripe-like area 23b which is shown as a space

20   and has a second phase value $\phi 2$ (e.g., zero degree).

       As shown in FIG. 8, a width of each stripe-like
area 23a or 23b varies along the longitudinal direction
(indicated by an arrow x). In other words, there is
a phase distribution that area shares of the first

25   stripe-like area 23a as a first area having the phase
value $\phi 1$ and the second stripe-like area 23b as
a second area having the phase value $\phi 2$ vary depending

on each position.

The incident light beams on the phase modulation element 1 are transmitted from a front surface of a paper sheet (front side) in a direction of a rear surface (inner side) of the same in FIG. 8 as indicated by an arrow z. This phase modulation element 1 can be manufactured by selecting a thickness of, e.g., a quartz glass so as to form the first and second phase values $\phi 1$ and $\phi 2$. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

As described above, the phase modulation element 1 shown in FIG. 8 has the phase distribution based on the phase modulation unit (stripe-like area) having an optically smaller width than the radius R/2 of the point spread distribution range R of the image formation optical system 3. Therefore, by appropriately changing the area shares of the first stripe-like area 23a and the second stripe-like area 23b in a unit range C optically corresponding to the point spread distribution range R of the image formation optical system 3, i.e., a sum of a plurality of phase vectors, a light intensity distribution formed on the processed substrate 4 can be controlled by using a predetermined calculation.

FIG. 9A is a view schematically showing yet another embodiment of the phase modulation element 1. Referring to FIG. 9A, the phase modulation element 1

has a line-and-space pattern 24 having an optically smaller width than a radius of the point spread distribution range R (see FIGS. 3B and 7, which is indicated by "C" in FIG. 9A) of the image formation

5 optical system 3. Incidentally, when this pattern is simply referred to as the line-and-space pattern, it generally means a set of a transmission area and a non-transmission area. However, in the present invention, it is notated as the line and space with

10 respect to a repetition of two different types of phases.

In FIG. 9A, each shaded line portion 24a has a first phase value $\phi1$ (e.g., 90 degrees), and each non-shaded space portion 24b shown as a space has

15 a second phase value $\phi2$ (e.g., zero degree). When a pitch is indicated with a ratio of a width of the line portion 24a and a width of the space portion 24b which are adjacent to each other, i.e., a part corresponding to the first phase value $\phi1$ and a part

20 corresponding to the second phase value $\phi2$ being regarded as a set, a percentage of the first phase value $\phi1$ in each pitch varies along a direction indicated by an arrow x.

Specifically, a duty ratio (width of the line

25 portion 24a/pitch) is 0% at the center of the line-and-space pattern 24, the duty ratio is linearly increased in increments of 5% toward a periphery, and the duty

ratio is 50% on the both sides. As described above,
the phase modulation element shown in FIG. 9A has
a phase distribution that area shares of the line
portion 24a as a first area having the phase value ϕ1
and the space portion 24b as a second area having the
phase value ϕ2 vary depending on each position like the
embodiment of the phase modulation element described
above.

As mentioned above, the phase modulation element 1
shown in FIG. 9A has the phase distribution based on
a phase modulation unit (the line portion or the space
portion) C having an optically smaller width than the
radius R/2 of the point spread distribution range R of
the image formation optical system 3. Therefore, by
appropriately changing the area shares of the line
portion 24a and the space portion 24b in the unit range
C optically corresponding to the point spread
distribution range R of the image formation optical
system 3, i.e., a sum of a plurality of phase vectors,
a light intensity distribution formed on the processed
substrate 4 (see FIG. 1) can be controlled by using
a predetermined calculation.

Specifically, as shown in FIG. 9A, a part in the
vicinity of the center in the longitudinal (arrow x)
direction is determined to substantially have the
second phase value ϕ2, and the line-and-space pattern
24 is formed in such a manner that a ratio of the area

having the first phase value $\phi 1$ is gradually increased toward the both end portions in a direction indicated by the arrow x. In this case, the incident light beams which are transmitted from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same as indicated by an arrow z demonstrate a light intensity distribution with a convex pattern that a light intensity becomes largest at the central position corresponding to the center of the line-and-space pattern 24 and the light intensity becomes smallest at positions on both sides corresponding to the both sides of the line-and-space pattern 24 as shown in FIG. 9B.

Actually, since the line-and-space pattern 24 is repeatedly formed along the both sides in the direction indicated by the arrow, there is obtained a light intensity distribution with a concave pattern that the light intensity is minimum at the center and the light intensity is one-dimensionally and substantially linearly increased toward the periphery, i.e., a light intensity distribution with a V-shaped (an alphabetical letter [V] and an inverted [V] are alternately arranged in zigzags) pattern. This phase modulation element 1 can be manufactured by selecting a thickness of, e.g., a quartz glass so as to form the first and second phase values $\phi 1$ and $\phi 2$. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

Incidentally, in order to obtain an accurately linear
light intensity distribution such as shown in FIG. 9B,
it is desirable for the areas 24a and 24b having the
different phase values to use a duty ratio (width of
5   the line portion 24a/pitch) which is obtained in
accordance with the expression (1) and non-linearly
increased (e.g., six steps of 0%, 5%, 11%, 18%, 28%
and 50%) in place of using a duty ratio which is
linearly increased as described above.

10   Meanwhile, when the processed substrate 4 is
irradiated with laser beams having a light intensity
with such a concave pattern as shown in FIG. 9B, there
is known a fact that a crystal nucleus is generated at
a position on the processed substrate 4 substantially
15   corresponding to a bottom portion (part where the light
intensity is minimum) of the light intensity
distribution. That is, a growth of a crystal (increase
in particle size) which is a change from an amorphia to
a crystal advances along a temperature gradient from
20   the crystal nucleus toward the periphery. At a part
where the light intensity of the laser beams with which
the processed substrate 4 is irradiated is not more
than a threshold value α, the semiconductor film (Si)
is not fused (remains as an amorphous material), or
25   a surface thereof is partially fused and the
semiconductor film remains in a silicon state (no
crystal growth), and the crystal growth starts when

the threshold value α is exceeded.

Therefore, in order to obtain a crystal with a large particle size which is as large as possible by adopting the light intensity distribution with the concave pattern, it is desirable that a value of the light intensity at the bottom of the light intensity distribution with the concave pattern is slightly lower than this value α. In other words, it is desirable that the value α used to obtain the crystal with a large particle size has the light intensity slightly larger than a bottom value of the light intensity distribution with the concave pattern. That is, the crystal is caused to grow in the lateral direction from the crystal nucleus by using the phase modulation element 1 shown in FIG. 9A to minimize the light intensity at a preset arbitrary position (form a bottom portion of the light intensity distribution) as shown in FIG. 9B and using the light intensity distribution with a pattern which increases the light intensity from the bottom portion toward the periphery in the light intensity distribution, thereby generating a crystal-lized semiconductor film with a large particle size.

In particular, since the temperature gradient toward the periphery also becomes linear in the light intensity distribution with a V-shaped pattern that the light intensity is linearly increased toward the periphery among the concave patterns, the growth of the

crystal does not stop, and a crystallized semiconductor film with a larger particle size can be generated. Furthermore, since an additional irregular light intensity distribution is not produced as different from the

5   prior art using the phase shifter as shown in FIG. 9B, crystal grains can be generated in an array form with a high filling ratio by using the light intensity distribution with the above-described pattern.

It is to be noted that the light intensity

10   distribution 24d having a concave pattern similar to the V-shaped pattern shown in FIG. 9B is not restricted to one axial direction and can be provided in an arbitrary direction by repeating the phase distribution shown in FIGS. 6A, 7 and 8 along a predetermined

15   direction (direction along which area shares vary). As a result, causing the lateral growth of the crystal from the crystal nucleus based on the light intensity distribution 24d having the same concave pattern as that shown in FIG. 9B can likewise generate

20   a crystallized semiconductor film with a large particle size by using the phase modulation element depicted in FIGS. 6A, 7 and 8.

As shown in FIG. 9C, it is to be noted that such a light intensity distribution to which an irregular

25   distribution is given in a plane direction as shown in FIG. 9C can be obtained by offsetting a position of the phase value $\phi 2$ by a predetermined quantity in

a direction indicated by an arrow y orthogonal to
a direction indicated by an arrow x in order to provide
a matrix form to the phase modulation element shown in
FIG. 9A. Moreover, in such a matrix type phase
modulation element as shown in FIG. 9C, a size of one
side of a phase modulation element block as a unit is,
e.g., 10 μm in the direction indicated by the arrow x
and 5 μm in the direction indicated by the arrow y.

FIG. 10A is a view schematically showing a further
structure of the phase modulation element according to
the present invention. Referring to FIG. 10A, the
phase modulation element 1 has a plurality of
rectangular pixels 25 each of which is optically
smaller than the radius R/2 of the point spread
distribution range R (i.e., a unit range C) of the
image formation optical system 3. The plurality of
pixels 25 are closely arranged in the both vertical and
horizontal direction, each pixel 25 has a fixed phase
value, and the phase value varies in accordance with
each pixel 25. In other words, the phase modulation
element 1 shown in FIG. 10A has a cyclic divided area
structure, each divided area (pixel) 25 has a fixed
phase value, and the phase modulation element 1 has a
phase distribution that the phase value varies in
accordance with each divided area.

Specifically, the phase modulation element 1 has
a first pixel 25a with a first phase value $\phi1$ (e.g.,

90 degrees), a second pixel 25b with a second phase value $\phi 2$ (e.g., 67.5 degrees), a third pixel 25c with a third phase value $\phi 3$ (e.g., 45 degrees), a fourth pixel 25d with a fourth phase value $\phi 4$ (e.g., 22.5 degrees), and a fifth pixel 25e with a fifth phase value $\phi 5$ (e.g., zero degree). Additionally, pixels other than the first to fifth pixels 25a to 25e have the same phase value (e.g., zero degree). That is, in the phase modulation element 1 shown in FIG. 10A, a change quantity of the phase value is small in an area on the fifth pixel 25e side having the fifth phase value $\phi 5$ given thereto, a change quantity of the phase value is large in an area on the first pixel 25a side having the first phase value $\phi 1$ given thereto, and a change quantity of the phase value monotonously varies between these areas. Therefore, as indicated by an arrow z, a light intensity of the light beams transmitted through the phase modulation element 1 from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same is larger on the fifth pixel 25e side than the first pixel 25a side as shown in FIG. 10B.

As described above, the phase modulation element 1 has a phase distribution based on a phase modulation unit (pixel) 25 having an optically smaller size than the radius R/2 of the point spread distribution range R (unit range C) of the image formation optical system 3.

Further, by appropriately changing the distribution of the phase values, i.e., a sum of a plurality of phase vectors, a light intensity distribution formed on the processed substrate 4 can be controlled by using a predetermined distribution. This phase modulation element 1 can be manufactured by selecting a thickness of, e.g., a quartz glass so as to form a desired phase value distribution. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

It is to be noted that repeating the phase distribution shown in FIG. 10A in a direction along which the phase value varies can provide a light intensity distribution similar to the V-shaped (an alphabetical letter [V] and an inverted [V] are alternately arranged in zigzags) pattern shown in FIG. 9B. As a result, the sufficient lateral growth of the crystal from a crystal nucleus can be realized based on the light intensity distribution with the concave pattern, thereby generating a crystallized semiconductor film with a large particle size.

FIG. 11A is a view schematically showing a still further structure of the phase modulation element according to the present invention. Referring to FIG. 11A, the phase modulation element 1 has a line-and-space pattern 26 having an optically smaller width than the radius R/2 of the point spread distribution

range R (unit range C) of the image formation optical

system 3.   Here, a duty ratio (width of a line

portion/pitch) is 50% and fixed over the entire line-

and-space pattern 26.   However, a phase value of each

5   shaded line portion varies in accordance with each line

portion.

That is, a phase value $\phi 1$ of the line portion 26a

is closest to a phase of the space portion at the

center of the line-and-space pattern 26, a phase value

10      $\phi 11$ of each line portion 26k on the both sides is

farthest from the phase of the space portion, and the

phase value of the line portion monotonously varies

between these values.   The phase value in each space

portion of the line-and-space pattern 26 is fixed.

15   Specifically, a phase value $\phi 1$ of a line portion 26a is

zero degree, a phase value $\phi 2$ of a line portion 26b is

25.9 degrees, a phase value $\phi 3$ of a line portion 26c is

36.9 degrees, a phase value $\phi 4$ of a line portion 26d is

45.6 degrees, a phase value $\phi 5$ of a line portion 26e is

20   53.2 degrees, and a phase value $\phi 6$ of a line portion

26f is 60.0 degrees.

Furthermore, a phase value $\phi 7$ of a line portion

26g is 66.5 degrees, a phase value $\phi 8$ of a line portion

26h is 72.6 degrees, a phase value $\phi 9$ of a line portion

25   26i is 78.5 degrees, a phase value $\phi 10$ of a line

portion 26j is 84.3 degrees, and a phase value $\phi 11$ of

a line portion 26k is 90.0 degrees.   On the other hand,

phase values of the respective space portions are all

zero degree. In this manner, the phase modulation

element 1 has a cyclic divided area structure, each

divided area (the line portion or the space portion)

5   has a fixed phase value, and the phase modulation

element 1 has a phase distribution that the phase value

varies in accordance with each divided area.

As described above, the phase modulation element 1

has a phase distribution based on a phase modulation

10   unit (the line portion or the space portion) having

an optically smaller width than the radius R/2 of

the point spread distribution range R of the image

formation optical system 3. Therefore, by

appropriately changing a distribution of the phase

15   values of the line portions in an optically smaller

unit range than the point spread distribution range R

of the image formation optical system 3, i.e., a sum of

a plurality of phase vectors, a light intensity

distribution formed on the processed substrate 4 (see

20   FIG. 4) can be controlled by using a predetermined

calculation. The incident light beams onto the phase

modulation element 1 are transmitted from a front

surface (front side) of a paper sheet in a direction of

a rear surface (inner side) of the same as indicated by

25   an arrow z in FIG. 11A. This phase modulation

element 1 can be readily manufactured by selecting

a thickness of, e.g., a quartz glass so as to form

a desired phase value distribution. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

Further, repeating the phase distribution shown in FIG. 11A along a predetermined direction (direction along which the phase value varies) can obtain a light intensity distribution with a concave pattern shown in FIG. 11B which is similar to the V-shaped pattern depicted in FIG. 9B, thereby forming crystal grains in an array form. As a result, the sufficient lateral growth from a crystal nucleus of a crystal can be realized based on the light intensity distribution with the concave pattern shown in FIG. 11A, thus generating a crystallized semiconductor film with a large particle size.

FIG. 12A is a schematic view illustrating a yet further embodiment of the phase modulation element according to the present invention. Referring to FIG. 12A, the phase modulation element 1 has a first stripe-like area 31 which has a first phase distribution and extends along a direction indicated by an arrow x which is a direction along which a phase varies, and a second stripe-like area 32 which has a second phase distribution and extends along the direction indicated by the arrow x in substantially parallel with the first stripe-like area 31 which is the direction along the phase varies. The first

stripe-like area 31 an the second stripe-like area 32

are adjacent to each other with a border line 33 in the

phase change direction therebetween, and an average

phase value on the first stripe-like area 31 side is

5   substantially different from an average phase value on

the second stripe-like area 32 side in a local area on

the border line 33. It is to be noted that light

intensity characteristics having a linear falling

gradient in directions indicated by arrows 31x and 32x

10   in FIG. 12A can be obtained based on, e.g., the phase

distribution shown in FIG. 11A.

The first stripe-like area 31 and the second

stripe-like area 32 are configured to have

substantially the same light intensity distributions

15   which are formed in accordance therewith. In a first

local area 34 on the border line 33 corresponding to a

part where the light intensity of the light intensity

distribution is small, an average phase value on the

first stripe-like area 31 side is substantially

20   different from an average phase value on the second

stripe-like area 32 side. On the other hand, in

a second local area 35 on the border line 33

corresponding to a part where the light intensity of

the light intensity distribution is large, an average

25   phase value ϕave on the first stripe-like area 31 side

is substantially equal to an average phase value ϕave

on the second stripe-like area 32 side. The average

phase value ϕave is represented by the following
expression:

$$\phi\text{ave} = \int_D \phi(x. \ y)dxdy$$

D is an integration range, and it is, e.g., a
range close to the center partitioned by the border
line 33 in the point spread distribution range R.
e(x, y) is a unit vector having a phase at coordinates
(x, y), and arg is a function used for obtaining the
phase from the vector.

The light beams transmitted through the phase
distribution pattern shown in FIG. 12A demonstrate
a light intensity distribution 120 with a concave
pattern having, e.g., a V-shaped (an alphabetical
letter [V] and an inverted [V] are alternately arranged
in zigzags) conformation along the phase change
direction in each of the first stripe-like area 31 and
the second stripe-like area 32 sufficiently distanced
from the border line 33 as shown in FIG. 12B.

A light intensity distribution along the border
line 33 shown in FIG. 12C produces a drop 121 in
a light intensity with an inverse peak pattern
corresponding to a part where the light intensity is
small in an area corresponding to the first local area
34 as described above in connection with FIGS. 3B to 3F
since the average phase value on the first stripe-like
area 31 side is substantially different from the
average phase value on the second stripe-like area 32

side in the first local area 34 on the border line 33.

However, since the average phase value on the first stripe-like area 31 side is substantially equal to the average phase value on the second stripe-like area 32 side in the second local area 35 on the border line 33, the affect by the second local area 35 is rarely produced in a part where the light intensity is large.

In the phase modulation element having the phase pattern shown in FIG. 12A, there is obtained a combined light intensity distribution of the light intensity distribution 120 with the concave pattern having, e.g., the V-shaped (an alphabetical letter [V] and an inverted [V] are alternately arranged in zigzags) conformation and the light intensity distribution with the inverse peak pattern 121 including a part where the light intensity is locally small in this light intensity distribution 120 with the concave pattern, i.e., a light intensity distribution with the concave pattern 120 and the inverse peak pattern locally including a part where the light intensity is locally small.

In the light intensity distribution with the concave pattern and the inverse peak pattern including the part where the light intensity is locally small, it is desirable to set the value α described with reference to FIG. 9B so as to be positioned in the

vicinity of the border between the light intensity
distribution 121 with the inverse peak pattern and the
light intensity distribution 120 with the concave
pattern or on the inner side of the light intensity

5   distribution 121 with the inverse peak pattern (to the
side where the light intensity is low). By setting the
position where the light intensity has the value α to
the above-described position (see FIG. 12A), a start
point of the crystal growth can be caused to

10   approximate the center of the light intensity
distribution 120 with the concave pattern including the
inverse peak pattern as much as possible, thereby
generating crystal grains with a large particle size.

Furthermore, a crystal nucleus formation position,

15   i.e., a crystal generation position can be controlled
to an arbitrary two-dimensional position by the effect
of the inverse peak pattern 121. The incident light
beams onto the phase modulation element 1 are
transmitted from a front surface (front side) of

20   a paper sheet in a direction of a rear surface (inner
side) of the same as indicated by an arrow z in
FIG. 12A. This phase modulation element 1 can be
manufactured by selecting a thickness of, e.g.,
a quartz glass so as to form a desired phase value

25   distribution. A change in thickness of the quartz
glass can be formed by selective etching or an FIB.

Moreover, in the phase modulation element having

the phase pattern shown in FIG. 12A, the light
intensity distribution 121 with the inverse peak
pattern is formed at a position where the light
intensity becomes minimum in the V-shaped (an
5   alphabetical letter [V] and an inverted [V] are
alternately arranged in zigzags) pattern as described
with reference to FIG. 12C due to a phase difference
between the two areas, i.e., a difference between the
average phase value on the first stripe-like area 31
10   side and the average phase value on the second stripe-
like area 32 side in the first local area 34 on the
border line 33. Since the first local area 13 is
linear, a low-light intensity area 36 formed on the
processed substrate 4 has an acute edge angle, as shown
15   in FIG. 13. With this structure, crystal grains 37 can
be easily generated in a very wide range. This
phenomenon is common to all phase modulation elements
whose border lines are based on the difference in
average phase values.

20   FIG. 14A is a view schematically showing another
structure of the phase modulation element according to
the present invention. Referring to FIG. 14A, even in
both a line-and-space pattern constituting a first
stripe-like area 31 of the phase modulation element 1
25   and a line-and-space pattern constituting a second
stripe-like area 32 of the same, a duty ratio (width of
a line portion/pitch) is 0% at the center, the duty

ratio is linearly increased in increments of 5% toward
the right-and-left peripheral direction, and the duty
ratio is 50% (a total of 11 steps) on the both sides.
It is to be noted that a size of one side of a phase

5   modulation element block as a unit in the phase
modulation element shown in FIG. 14A is, e.g., 10 μm in
a direction indicated by an arrow x and 5 μm in a
direction indicated by an arrow y in terms of values
converted to the image formation surface.

10   In the line-and-space pattern of the first
stripe-like area 31, each shaded line portion has
a first phase value $\phi 1$ (e.g., 90 degrees) and each
non-shaded space portion shown as a space has a second
phase value $\phi 2$ (e.g., zero degree). On the other hand,

15   the line-and-space pattern of the second stripe-like
area 32 is a phase distribution that each shaded line
portion has a third phase value $\phi 3$ (e.g., -90 degrees)
and each non-shaded space portion shown as a space has
a second phase value $\phi 2$ (e.g., zero degree).

20   That is, the phase modulation element 1 shown in
FIGS. 14A and 14B has a structure that the first
stripe-like area 31 that a superficial content of
an area having a phase value of 90° is gradually
increased from the center along the arrow x and the

25   second stripe-like area 32 that a superficial content
of an area having a phase value of -90° is gradually
increased from the center along the arrow x are

connected with each other along a border line 33.

In this manner, in the phase modulation element 1 shown in FIGS. 14A and 14B, the first stripe-like area 31 and the second stripe-like area 32 are configured to have substantially the same light intensity distributions which are formed in accordance therewith. In a first local area 34 on the border line 33 corresponding to a part where the light intensity of the light intensity distribution is small, an average phase value (e.g., approximately 45 degrees) on the first stripe-like area 31 side is substantially different from an average phase value (e.g., approximately -45 degrees) on the second stripe-like area 32 side. On the other hand, in a second local area 35 on the border line 33 corresponding to a part where the light intensity of the light intensity distribution is large, an average phase value (e.g., approximately zero degree) on the first stripe-like area 31 side is substantially equal to an average phase value (e.g., approximately zero degree) on the second stripe-like area 32 side. The incident light beams onto the phase modulation element 1 are transmitted from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same as indicated by an arrow z in FIG. 14A. This phase modulation element 1 can be readily manufactured by selecting a thickness of, e.g., a quartz glass so as to

form a desired phase value distribution. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

As described above, according to the phase modulation element shown in FIGS. 14A and 14B, such a light intensity distribution with a concave pattern as shown in FIG. 14B can be obtained in a direction along which the phase varies in each of the first stripe-like area 31 and the second stripe-like area 32 sufficiently distanced from the border line 33 like the phase modulation element described in connection with FIG. 12A.

FIG. 15A is a schematic view showing in a contour map a light intensity distribution obtained in the phase modulation element depicted in FIG. 14A, FIG. 15B shows a light intensity distribution along the line A-A in FIG. 15A, and FIG. 15C shows a light intensity distribution along the border line B-B in FIG. 15A, respectively. It is to be noted that an image side numerical aperture NA of the image formation optical system 3 (see FIG. 3A) is set to 0.13 and an illumination sigma value (numerical aperture of the illumination system/object side numeral aperture of the image formation optical system 3) is set to 0.43.

Comparing the FIG. 15B light intensity distribution along the line A-A in FIG. 15A with the FIG. 15C light intensity distribution along

the line B-B in FIG. 15A, it can be understood that
a drop in light intensity which has an inverse peak
pattern shape is formed at a part where the light
intensity is small corresponding to a first local

5   area 34. That is, it can be recognized that the light
intensity distribution with a concave pattern suitable
for crystallization and an inverse peak pattern that
a light intensity is smaller than a threshold value α
is actually obtained by irradiating the processed

10   substrate with laser beams by using the phase
modulation element having the phase value pattern shown
in FIG. 14A.

　　　　FIG. 16A is a view schematically showing still
another structure of the phase modulation element

15   according to the present invention. Referring to
FIG. 16A, even in both a line-and-space pattern
constituting a first stripe-like area 31 of the phase
modulation element 1 and a line-and-space pattern
constituting a second stripe-like area 32 of the same,

20   a duty ratio (width of a line portion/pitch) is 50%
(a total of 11 steps) and fixed over the entire
patterns.

　　　　In the line-and-space pattern of the first
stripe-like area 31, a phase value $\phi 1$ of the line

25   portion is closest to a phase of the space portion at
the center thereof, a phase value $\phi 11$ of the line
portion on each of the both sides is farthest from

the phase of the space portion, and the phase value of the line portion monotonously varies between these areas. Specifically, the phase value $\phi 1$ is zero degree, a phase value $\phi 2$ is 25.9 degrees, a phase value $\phi 3$ is 36.9 degrees, a phase value $\phi 4$ is 45.6 degrees, a phase value $\phi 5$ is 53.2 degrees, a phase value $\phi 6$ is 60.0 degrees, a phase value $\phi 7$ is 66.5 degrees, a phase value $\phi 8$ is 72.6 degrees, a phase value $\phi 9$ is 78.5 degrees, a phase value $\phi 10$ is 84.3 degrees, and the phase value $\phi 11$ is 90.0 degrees.

On the other hand, in the line-and-space pattern of the second stripe-like area 32, a phase value ϕ-1 of the line portion is closest to a phase of the space portion at the center thereof, a phase value ϕ-11 of the line portion on each of the both sides is farthest from the phase of the space portion, and the phase value of the line portion monotonously varies between these areas. Specifically, the phase value ϕ-1 is zero degree, a phase value ϕ-2 is 25.9 degrees, a phase value ϕ-3 is 36.9 degrees, a phase value ϕ-4 is 45.6 degrees, a phase value ϕ-5 is 53.2 degrees, a phase value ϕ-6 is 60.0 degrees, a phase value ϕ-7 is 66.5 degrees, a phase value ϕ-8 is 72.6 degrees, a phase value ϕ-9 is 78.5 degrees, a phase value ϕ-10 is 84.3 degrees, and the phase value ϕ-11 is -90.0 degrees. However, both in the line-and-space pattern constituting the first stripe-like area 31 and

the line-and-space pattern constituting the second
stripe-like area 32, the phase values of the respective
space portion are all zero degree.

It is to be noted that a size of one side of
a phase modulation element block as a unit in the phase
modulation element shown in FIG. 16A is, e.g., 10 μm in
a direction indicated by an arrow x and 5 μm in
a direction indicated by an arrow y in terms of values
converted to the image formation surface.

In the phase modulation element shown in FIGS. 16A
and 16B, the first stripe-like area 31 and the second
stripe-like area 32 are configured to have
substantially the same light intensity distributions
which are formed in accordance therewith. In this
phase modulation element, an average phase value (e.g.,
approximately 45 degrees) on the first stripe-like
area 31 side is substantially different from an average
phase value (e.g., approximately -45 degrees) on
the second stripe-like area 32 side in a first local
area 34 on a border line 33 corresponding to a part
where the light intensity in the light intensity
distribution is small. On the other hand, in a second
local area 35 on the border line 33 corresponding to
a part where the light intensity in the light intensity
distribution is large, an average phase value (e.g.,
approximately zero degree) on the first stripe-like
area 31 side is substantially equal to an average phase

value (e.g., approximately zero degree) on the second
stripe-like area 32 side. The light beams entering the
phase modulation element 1 are transmitted from a front
surface (front side) of a paper sheet in a direction of
a rear surface (inner side) of the same as indicated by
an arrow z in FIG. 16A. This phase modulation element
1 can be manufactured by selecting a thickness of,
e.g., a quartz glass so as to form a desired phase
value distribution. A change in thickness of the
quartz glass can be formed by selective etching or
an FIB.

As described above, according to the phase
modulation element shown in FIGS. 16A and 16B, there is
obtained such a light intensity distribution with a
concave pattern as shown in FIG. 12B in a direction
along which the phase varies in each of the first
stripe-like area 31 and the second stripe-like area 32
sufficiently distanced from the border line 33 like the
phase modulation element described above with reference
to FIG. 12A. Moreover, a drop in light intensity which
has an inverse peak pattern shape with a small light
intensity corresponding to the first local area 34 is
formed along the border line 33 as shown in FIG. 12C.
As a result, it is possible to obtain the light
intensity distribution with a concave pattern suitable
for crystallization and an inverse peak pattern that
the light intensity is smaller than a threshold

value α.

FIG. 17A shows in a contour map a light intensity distribution obtained in the phase modulation element depicted in FIG. 16A, FIG. 17B shows a light intensity distribution along the line A-A in FIG. 17A, and FIG. 17C shows a light intensity distribution along the line B-B in FIG. 17A, respectively. It is to be noted that an image side numerical aperture NA of the image formation optical system 3 is set to 0.13 and an illumination sigma value is set to 0.43.

Comparing the FIG. 17B light intensity distribution along the line A-A in FIG. 17A with the FIG. 17C light intensity distribution along the line B-B in FIG. 17A parallel with the border line 33, it can be understood that a drop in light intensity with an inverse peak pattern shape is formed at a part where the light intensity is small corresponding to the first local area 34. That is, it can be recognized that a light intensity distribution with a concave pattern suitable for crystallization and an inverse peak pattern that the light intensity is smaller than a threshold value α is actually obtained by irradiating the processed substrate with the laser beams by using the phase modulation element having the phase value pattern shown in FIG. 16A.

FIG. 18A is a view schematically showing yet another structure of the phase modulation element

according to the present invention. Referring to

FIG. 18A, to the phase modulation element 1 are

provided a stripe-like area 41 which has a

predetermined phase distribution and extends along a

5   direction indicated by an arrow x which is a direction

along which the phase varies and isolated areas 42 each

of which has a phase value substantially different from

that of the periphery in accordance with a part where

the light intensity is small in a light intensity

10   distribution formed by the effect of the stripe-like

area 41. The isolated area 42 is an area which has

an optically smaller size than a radius of a unit

range C optically corresponding to the point spread

distribution range R of the image formation optical

15   system 3 and has a large phase difference.

By using the phase modulation element shown in

FIG. 18A, a light intensity of light beams which are

transmitted through an area separated from the isolated

area 42 by a predetermined distance in a direction

20   indicated by an arrow y varies with a linearly falling

gradient (characteristics that the light intensity

becomes maximum at an intermediate position of the

isolated areas 42 and the light intensity is gradually

decreased toward a position separated from the isolated

25   areas 42 by a predetermined distance in the direction

indicated by an arrow y) in a direction indicated by

an arrow x, the light intensity having a minimum value

at a position separated from the isolated areas 42 by

a predetermined distance in the direction indicated by

the arrow y and the light intensity having a maximum

value in the vicinity of an intermediate position

5   between the isolated areas 42 in a direction

along which the phase varies, as shown in FIG. 18B.

In other words, there is obtained a light intensity

distribution with a concave pattern having the V-shaped

(an alphabetical letter [V] and an inverted [V] are

10   alternately arranged in zigzags) conformation.

As to the light intensity of the light beams in

the direction indicated by the arrow x transmitted

through the isolated areas 42, a drop in light

intensity with an inverse peak pattern shape including

15   a part where the light intensity is locally small is

formed at the part where the light intensity is small

corresponding to each isolated area 42 by the effect of

the isolated area 40 (since a phase value of each

isolated area 42 is substantially different from

20   a phase value of the periphery thereof) as shown in

FIG. 18C when the phase modulation element depicted in

FIG. 18A is used.

In regard to the phase distribution of the phase

modulation element 1 to obtain a V-shaped light

25   distribution pattern shown in FIG. 18B, using, e.g.,

the pattern shown in FIG. 11A can suffice. The light

beams entering the phase modulation element 1 are

transmitted from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same as indicated by an arrow z in FIG. 18A. This phase modulation element 1 can be

5   manufactured by selecting a thickness of, e.g., a quartz glass so as to form a desired phase value distribution. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

As described above, by using the phase modulation

10 element shown in FIG. 18A, there is obtained a combined light intensity distribution resulting from the light intensity distribution 181 with a concave pattern having, e.g., the V-shaped (an alphabetical letter [V] and an inverted [V] are alternately arranged in

15 zigzags) and the light intensity distribution 182 with an inverse peak pattern including a part where the light intensity is locally small in the part where the light intensity is small in this light intensity distribution 181 with the concave pattern, i.e.,

20 a combined light intensity distribution with the concave pattern and the inverse peak pattern including the part where the light intensity is locally small shown in FIG. 18C.

As a result, a start point of the crystal growth

25 can be caused to approximate the center of the light intensity distribution having the part where the light intensity is locally small as much as possible, thereby

generating crystal grains with a large particle size.

Moreover, a crystal generation position can be

controlled to an arbitrary two-dimensional position.

Additionally, it is possible to effect crystallization

5   that the lateral growth with a large particle size is

achieved by positioning the inverse peak pattern 182

including the part where the light intensity is locally

small to, e.g., a seed crystal position in order to

carry out crystallization. The isolated area 42 is not

10   restricted to a square shape, and any shape such as

a circular shape or a triangular shape can be used.

FIG. 19A is a view schematically showing a further

structure of the phase modulation element according to

the present invention. Referring to FIG. 19A, in

15   a line-and-space pattern constituting a stripe-like

area 41 of the phase modulation element 1, a duty ratio

(width of a line portion/pitch) is 100% at the center

thereof, the duty ratio is linearly decreased 5% at

a time toward the periphery, and the duty ratio is 50%

20   on each of the both sides.

In the phase modulation element shown in FIG. 19A,

each shaded line portion has a first phase value $\phi 1$

(e.g., 90 degrees), each non-shaded space portion shown

as a space has a second phase value $\phi 2$ (e.g., zero

25   degree), and each isolated area 42 has a third phase

value $\phi 3$ (e.g., 225 degrees). As apparent from

FIG. 19A, each isolated area 42 is arranged in

accordance with a part where the light intensity is small in a light intensity distribution formed by the effect of the stripe-like area 41, and has a phase value substantially different from that of the

5   periphery. The light beams entering the phase modulation element 1 are transmitted from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same as indicated by an arrow z in FIG. 19A. This phase modulation element

10   1 can be readily manufactured by selecting a thickness of, e.g., a quartz glass so as to form a desired phase value distribution. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

15   By using the phase modulation element shown in FIG. 19A, the light intensity of the light beams transmitted through an area separated from each isolated area 42 by a predetermined distance in a direction indicated by an arrow y varies with

20   a linearly falling gradient (characteristics that the light intensity becomes maximum at an intermediate position of the isolated areas 42 and the light intensity is gradually decreased toward a position separated from the isolated areas 42 by a predetermined

25   distance in the direction indicated by the arrow y) in a direction indicated by an arrow x, the light intensity having a minimum value at a position

separated from the isolated areas 42 by a predetermined

distance in the direction indicated by the arrow y and

the light intensity having a maximum value in the

vicinity of an intermediate position between the

5   isolated areas 42 in parallel with a direction along

which the phase values as shown in FIG. 19B. That is,

there is obtained a light intensity distribution with

a concave pattern having a V-shaped (an alphabetical

letter [V] and an inverted [V] are alternately arranged

10   in zigzags) conformation. Additionally, a drop in

light intensity having an inverse peak pattern shape

including a part where the light intensity is locally

small is formed at the part where the light intensity

is small corresponding to each isolated area along

15   a cross section including the isolated areas 42 as

shown in FIG. 19C. As a result, it is possible to

obtain a light intensity distribution with a concave

pattern suitable for crystallization and an inverse

peak pattern including a part where the light intensity

20   is locally small.

      FIG. 20A shows a contour map of a light intensity

distribution obtained in the phase modulation element

depicted in FIG. 19A, FIG. 20B shows a light intensity

distribution along the line A-A in FIG. 20A, and

25   FIG. 20C shows a light intensity along the line B-B in

FIG. 20A, respectively. It is to be noted that

an image side numerical aperture NA of the image

formation optical system 3 is set to 0.13 and
an illumination sigma value is set to 0.43.

Comparing the FIG. 20B light intensity
distribution along the line A-A in FIG. 20A with

5   the FIG. 20C light intensity distribution along the
line B-B in FIG. 20A parallel with the cross section
including the isolated areas 42, it can be understood
that a drop in light intensity having an inverse peak
pattern shape which includes a part where the light

10   intensity is locally small is formed at the part where
the light intensity is small corresponding to each
isolated area 42. That is, it can be recognized that
a light intensity distribution with a concave pattern
suitable for crystallization and an inverse peak

15   pattern that the light intensity is smaller than
a threshold value α is actually obtained by irradiating
the processed substrate with laser beams by using the
phase modulation element having the phase value pattern
shown in FIG. 20A.

20   FIG. 21A is a view schematically showing a still
further structure of the phase modulation element
according to the present invention. Referring to
FIG. 21A, in a pattern constituting a first stripe-like
area 31 of the phase modulation element 1, each

25   shaded rectangular area has a phase value of, e.g.,
90 degrees, and a non-shaded area shown as a space has
a phase value of, e.g., zero degree. On the other

hand, in a pattern constituting a second stripe-like area 32, each shaded rectangular area has a phase value of, e.g., -90 degrees, and a non-shaded area shown as a space has a phase value of, e.g., zero degree.

The first stripe-like area 31 and the second stripe-like area 32 are configured to have substantially the same light intensity distributions which are formed in accordance therewith.

The light beams entering the phase modulation element 1 are transmitted from a front surface (front side) of a paper sheet in a direction of a rear surface (inner side) of the same as indicated by an arrow z in FIG. 21A. This phase modulation element 1 can be readily manufactured by selecting a thickness of, e.g., a quartz glass so as to form first and second phase values $\phi 1$ and $\phi 2$. A change in thickness of the quartz glass can be formed by selective etching or an FIB.

In the phase modulation element shown in FIG. 21A, an average phase value (e.g., approximately 45 degrees) on the first stripe-like area 31 side is substantially different from an average value (e.g., approximately -45 degrees) on the second stripe-like area 32 side in a first local area 34 defined on a border line 33 corresponding to a part where the light intensity in the light intensity distribution is small. On the other hand, in a second local area 35 defined on the border line 33 corresponding to a part

where the light intensity in the light intensity
distribution is large, an average phase value (e.g.,
approximately zero degree) on the first stripe-like
area 31 side is substantially equal to an average phase
5   value (e.g., approximately zero degree) on the second
stripe-like area 32 side.

     By using the phase modulation element shown in
FIG. 21A, the light intensity of the light beams
passing through an area (cross section along the
10   line A-A) separated from the border line 33 by
a predetermined distance in a direction indicated by
an arrow y varies with a linearly falling gradient
(characteristics that the light intensity becomes
maximum at a position separated from the second local
15   area 35 by a predetermined distance in the direction
indicated by the arrow y and the light intensity is
gradually decreased toward a position separated
from the first local area 34 by a predetermined
distance in the direction indicated by the arrow y)
20   in a direction indicated by an arrow x, the light
intensity having a maximum value at a position
separated from the second local area 35 by a
predetermined distance in the direction indicated by
the arrow y and the light intensity having a minimum
25   value at a position separated from the first local
area 34 by a predetermined distance in the direction
indicated by the arrow y, as shown in FIG. 21B.

That is, there is obtained a light intensity
distribution with a concave pattern having a V-shaped
(an alphabetical letter [V] and an inverted [V] are
alternately arranged in zigzags) conformation.

5   Further, the light intensity of the light beams passing
along the border line 33, i.e., the cross section
including the first local area 34 and the second local
area 35 takes a maximum value in an area corresponding
to the second local area 35, and takes a minimum value

10   in an area corresponding to the first local area 34.
It is to be noted that a drop in light intensity having
an inverse peak pattern shape which includes a part
where the light intensity is locally small is formed in
the area corresponding to the first local area 34.

15   That is, there can be obtained a light intensity
distribution with a concave pattern suitable for
crystallization and an inverse peak pattern including
a part where the light intensity is locally small.

        FIG. 22A is a view schematically showing a yet
20   further structure of the phase modulation element
according to the present invention. Referring to
FIG. 22A, in a pattern constituting a stripe-like area
41 of the phase modulation element 1, each shaded
rectangular area has a phase value of, e.g.,   -

25   90 degrees, and a non-shaded area shown as a space has
a phase value of, e.g., zero degree. Furthermore,
each isolated area 42 having a phase value (e.g.,

225 degrees) substantially different from that of
the periphery is provided in accordance with a part
where a light intensity is small in a light intensity
distribution formed by the effect of the stripe-like
5   area 41. As apparent from FIG. 22A, each isolated
area 42 is arranged in accordance with the part where
the light intensity is small in the light intensity
distribution formed by the effect of the stripe-like
area 41, and has a phase value substantially different
10   from that of the periphery. The light beams entering
the phase modulation element 1 are transmitted from
a front surface (front side) of a paper sheet in
a direction of a rear surface (inner side) of the same
as indicated by an arrow z in FIG. 22A. This phase
15   modulation element 1 can be readily manufactured by
selecting a thickness of, e.g., a quartz glass so as to
form a desired phase value distribution. A change in
thickness of the quartz glass can be formed by
selective etching or an FIB.

20   By using the phase modulation element shown in
FIG. 22A, the light intensity of the light beams which
pass through an area separated from each isolated
area 42 by a predetermined distance in a direction
indicated by an arrow y varies with a linearly falling
25   gradient (characteristics that the light intensity
becomes maximum at an intermediate position of
the isolated areas 42 and the light intensity is

gradually decreased toward a position separated from

each isolated area 42 by a predetermined distance in

the direction indicated by the arrow y) in a direction

indicated by an arrow x with the light intensity having

5   a minimum value at a position separated from each

isolated area 42 by a predetermined distance in the

direction indicated by the arrow y and the light

intensity having a maximum value in the vicinity of the

intermediate position between the isolated areas 42 in

10   parallel with a direction along which the phase varies,

as shown in FIG. 22B. That is, there is obtained

a light intensity distribution with a concave pattern

having a V-shaped (an alphabetical letter [V] and

an inverted [V] are alternately arranged in zigzags)

15   conformation. Furthermore, a drop in light intensity

with an inverse peak pattern shape including a part

where the light intensity is locally small is formed at

the part where the light intensity is small

corresponding to each isolated area 42, as shown in

20   FIG. 22C. As a result, it is possible to obtain

a light intensity distribution with a concave pattern

suitable for crystallization and an inverse peak

pattern including the part where the light intensity is

locally small.

25   FIG. 23A is a view schematically showing another

structure of the phase modulation element according to

the present invention. Referring to FIG. 23A, in

a pattern constituting a stripe-like area 41of the

phase modulation element 1, each shaded line portion

has a phase value of, e.g., 90 degrees, and each

non-shaded space portion shown as a space has a phase

5   value of, e.g., zero degree, and isolated areas 42 each

having a phase value (e.g., 225 degrees) substantially

different from that of the periphery are provided in

accordance with parts having the small light intensity

in a light intensity distribution formed by the effect

10   of the stripe-like area 41. The light beams entering

the phase modulation element 1 are transmitted from

a front surface (front side) of a paper sheet in

a direction of a rear surface (inner side) of the same

as indicated by an arrow z in FIG. 23A. This phase

15   modulation element 1 can be readily manufactured by

selecting a thickness of, e.g., a quartz glass so as to

form a desired phase value distribution. A change in

thickness of the quartz glass can be formed by

selective etching or an FIB.

20   By using the phase modulation element shown in

FIG. 23A, a light intensity of the light beams passing

through an area separated from each isolated area 42 by

a predetermined distance in a direction indicated by

an arrow y varies with a linearly falling gradient

25   (characteristics that the light intensity becomes

maximum at an intermediate position of the isolated

areas 42 and the light intensity is gradually decreased

toward a position separated from each isolated area 42
by a predetermined distance in the direction indicated
by an arrow y) in a direction indicated by an arrow x,
the light intensity having a minimum value at

5   a position separated from each isolated area 42 by
a predetermined position in the direction indicated by
the arrow y and the light intensity having a maximum
value in the vicinity of the intermediate position
between the isolated areas 42 in parallel with

10   a direction along which the phase varies, as shown in
FIG. 23B. That is, there is obtained a light intensity
distribution with a concave pattern having a V-shaped
(an alphabetical letter [V] and an inverted [V] are
alternately arranged in zigzags) conformation.

15   Moreover, a drop in light intensity with an inverse
peak pattern shape including a part where the light
intensity is locally small is formed at the part where
the light intensity is small corresponding to each
isolated area 42 along a cross section including each

20   isolated area 42. As a result, there can be obtained
a light intensity distribution with a concave pattern
suitable for crystallization and an inverse peak
pattern including the part where the light intensity is
locally small.

25   FIG. 24A is a view schematically showing still
another structure of the phase modulation element
according to the present invention. Referring to

FIG. 24A, in a pattern constituting a stripe-like area
41 of the phase modulation element 1, a phase value of
each shaded line portion varies in a range between,
e.g., zero degree and 90 degrees in accordance with

5   each line portion, and each non-shaded space portion
shown as a space has a phase value of, e.g., zero
degree. It is to be noted that each isolated area 42
having a phase value (e.g., 225 degrees) substantially
different from that of the periphery is provided in

10   accordance with a part having a small light intensity
in a light intensity distribution formed by the effect
of the stripe-like area 41. The light beams entering
the phase modulation element 1 are transmitted from
a front surface (front side) of a paper sheet in

15   a direction of a rear surface (inner side) of the same
as indicated by an arrow z in FIG. 24A. This phase
modulation element 1 can be readily manufactured by
selecting a thickness of, e.g., a quartz glass so as to
form a desired phase value distribution. A change in

20   thickness of the quartz glass can be formed by
selective etching or an FIB.

By using the phase modulation element shown in
FIG. 24A, a light intensity of the light beams passing
through an area separated from each isolated area 42 by

25   a predetermined distance in a direction indicated by
an arrow y varies with a linearly falling gradient
(characteristics that the light intensity becomes

maximum at an intermediate position of the isolated

areas 42 and the light intensity is gradually decreased

toward a position separated from each isolated area 42

by a predetermined distance in the direction indicated

5   by the arrow y) in a direction indicated by an arrow x,

the light intensity having a minimum value at

a position separated from each isolated area 42 by

a predetermined distance in the direction indicated by

the arrow y and the light intensity having a maximum

10   value in the vicinity of the intermediate position

between the isolated areas 42 in parallel with

a direction along which the phase varies, as shown in

FIG. 24B. That is, there is obtained a light intensity

distribution with a concave pattern having a V-shaped

15   (an alphabetical character [V] and an inverted [V] are

alternately arranged in zigzags) conformation.

Furthermore, a drop in light intensity with an inverse

peak pattern shape including a part where the light

intensity is locally small is formed at the part where

20   the light intensity is small corresponding to each

isolated area 42 as shown in FIG. 24C. As a result,

there can be obtained a light intensity distribution

with a concave pattern suitable for crystallization and

an inverse peak pattern including the part where the

25   light intensity is locally small.

FIG. 25A is a view schematically showing yet

another structure of the phase modulation element

according to the present invention. Referring to

FIG. 25A, in a pattern constituting a stripe-like

area 41 of the phase modulation element 1, each shaded

stripe-like area has a phase value of, e.g.,

5   90 degrees, each non-shaded area shown as a space has

a phase value of, e.g., zero degree, and isolated

areas 42 each having a phase value (e.g., 225 degrees)

substantially different from that of the periphery are

provided in accordance with parts each having a small

10   light intensity in a light intensity distribution

formed by the effect of the stripe-like area 41.

The light beams entering the phase modulation element 1

are transmitted from a front surface (front side) of

a paper sheet in a direction of a rear surface (inner

15   side) of the same as indicated by an arrow z in

FIG. 25A. This phase modulation element 1 can be

readily manufactured by selecting a thickness of, e.g.,

a quartz glass so as to form first and second phase

values $\phi 1$ and $\phi 2$. A change in thickness of the quartz

20   glass can be formed by selective etching or an FIB.

By using the phase modulation element shown in

FIG. 25A, a light intensity of the light beams passing

through an area separated from each isolated area 42 by

a predetermined distance in a direction indicated by

25   an arrow y varies with a linearly falling gradient

(characteristics that the light intensity becomes

maximum at an intermediate position of the isolated

areas 42 and the light intensity is gradually decreased
toward a position separated from each isolated area 42
by a predetermined distance in the direction indicated
by the arrow y) in a direction indicated by an arrow x,
the light intensity having a minimum value at the
position separated from each isolated area 42 by
a predetermined distance in the direction indicated by
the arrow y and the light intensity having a maximum
value in the vicinity of the intermediate position
between the isolated areas 42 in parallel with
a direction along which the phase varies, as shown in
FIG. 25B. That is, there is obtained a light intensity
distribution with a concave pattern having a V-shaped
(an alphabetical letter [V] and an inverted [V] are
alternately arranged in zigzags) conformation.
Moreover, as shown in FIG. 25C, a drop in light
intensity with an inverse peak pattern shape including
a part where the light intensity is locally small is
formed at the part where the light intensity is small
corresponding to each isolated area 42 along a cross
section including each isolated area 42. As a result,
there can be obtained a light intensity distribution
with a concave pattern suitable for crystallization and
an inverse peak pattern including the parts where the
light intensity is locally small.

It is to be noted that the example that the phase
modulation element 1 takes the finite number of phase

values are described in the above various embodiments
but the phase value may continuously vary. For
example, when interpolation processing is carried out
by using an arbitrary method in order to substitute the
stepped distribution of the phase modulation element 1
in the foregoing embodiments for a smooth curved
surface, the equivalent advantages can be obtained.

Additionally, the phase modulation element 1 can
be realized by an irregular shape corresponding to a
phase value by using a technique to manufacture a
regular phase shift mask.

Further, the phase modulation element 1 can be
also realized by using a distribution of refractive
indices of a material as well as the irregular shape.

Furthermore, the phase modulation element 1 such
as a liquid crystal element or a micro mirror device
which can vary a phase modulation quantity may be
realized.

Moreover, in the foregoing embodiments, the light
intensity distribution can be calculated on a design
stage, but it is desirable to observe and confirm the
light intensity distribution on an actual processed
surface. In order to realize this, it is good enough
to magnify the processed surface of the processed
substrate 4 by using the optical system and input a
result by utilizing an imaging element such as a CCD.
Incidentally, if the light beams to be used are

ultraviolet rays, the optical system including a CCD
element and others may be possibly restricted in
sensitivity or photoelectric conversion efficiency.
Therefore, a fluorescent screen may be provided on the
5   processed surface only during observation in order to
convert the light beams into visible light beams.
Additionally, although the concrete structural examples
of the phase modulation element 1 have been described
in connection with the foregoing embodiments, various
10   kinds of modifications of the structure of the phase
modulation element 1 can be carried out within the
scope of the present invention.

FIGS. 26A to 26E are process cross-sectional views
showing steps to manufacture an electronic device in an
15   area (processed surface) crystallized by using the
crystallization apparatus according to this embodiment.

As shown in FIG. 26A, there is prepared a
processed substrate 4 having an underlying film 81
(e.g., SiN having a film thickness of 50 nm and an SiO_2
20   laminated film having a film thickness of 100 nm) and
an amorphous semiconductor film 82 (e.g., Si, Ge, SiGe
and others each having a film thickness of
approximately 50 nm to 200 nm) formed on an insulated
substrate 80 (e.g., alkali glass, quartz glass, plastic
25   or polyimide) by using chemical vapor deposition or
a sputtering method.

Subsequently, all or a part of a surface of the

amorphous semiconductor film 82, e.g., a predetermined

area is irradiated with laser beams 83 (e.g., KrF

excimer laser beams or an XeCl excimer laser beams) by

using the crystallization apparatus shown in FIG. 1

5   through the phase modulation element 1 according to the

above-described various kinds of conformations, e.g.,

the phase modulation element 1 shown in FIG. 9C.

Therefore, a polycrystal semiconductor film or

a single-crystallized semiconductor film 84 having

10   a crystal with a large particle size is generated as

shown in FIG. 26B.

Then, as shown in FIG. 26C, the polycrystal

semiconductor film or the single-crystallized

semiconductor film 84 is processed into an island-

15   shaped semiconductor film 85 which becomes an area used

to form, e.g., a thin film transistor by using

a photolithography technique, and an SiO_2 film having

a film thickness of 20 nm to 100 nm as a gate

insulating film 86 is formed on a surface of the

20   semiconductor film 85 by using, e.g., chemical vapor

deposition or a sputtering method.

Further, as shown in FIG. 26D, a gate electrode 87

(e.g., silicide or MoW) is formed on the gate

insulating film, impurity ions 88 (phosphorous in case

25   of an N channel transistor, and boron in case of a P

channel transistor) are implanted with the gate

electrode 87 being used as a mask.   Thereafter,

although not shown, annealing processing is carried out
in a nitrogen atmosphere (e.g., one hour at 450°C), and
the impurities are activated, thereby forming a source
area 91 and a drain area 92 in the island-shaped

5   semiconductor film 85.

Then, as shown in FIG. 26E, for example, an
interlayer insulating film 89 is formed, contact holes
are formed, and a source electrode 93 and a drain
electrode 94 connected with a source 91 and a drain 92

10   which are connected through a channel 90 are formed.

In the above-described steps, a channel 90 is
formed in accordance with a position of a crystal with
a large particle size of the polycrystal semiconductor
film or the single-crystallized semiconductor film 84

15   generated in the steps shown in FIGS. 26A and 26B.

Based on the above-described steps, a thin film
transistor (TFT) can be formed to the polycrystal
transistor or the single-crystallized semiconductor.

The polycrystal transistor or the single-

20   crystallized transistor manufactured in the steps shown
in FIGS. 26A to 26E can be applied to a drive circuit
for, e.g., a liquid crystal display (display) or an EL
(electroluminescence) display, or an integrated circuit
for a memory (SRAM or DRAM) or a CPU.

25   A description will now be given as to
an embodiment that a base material including an area
crystallized by using the crystallization apparatus

according to this embodiment is applied to a display

apparatus, e.g., a liquid crystal display.

A method for forming a display apparatus including

TFTs will now be described hereinafter.

5   FIGS. 26 and 28 show a display apparatus, e.g.,

an active matrix type liquid crystal display.

The display apparatus 220 will be referred to as

a liquid crystal display hereinafter.

First, the liquid crystal display 220 will be

10   described. The liquid crystal display 220 comprises

a pair of front and rear transparent base substances

221 and 222, a liquid crystal layer 223, pixel

electrodes 224, scanning wirings 225, signal wirings

226, an opposed electrode 227, TFTs 230 and others.

15   As the pair of transparent base substances 221 and

222, a pair of glass sheets can be used, for example.

These transparent base substances 221 and 222 are

joined through a non-illustrated frame-shaped sealing

material. The liquid crystal layer 223 is provided to

20   an area surrounded by the sealing material between the

pair of transparent base substances 221 and 222.

On the inner surface of one of the pair of

transparent base substances 221 and 222, e.g., the

transparent base substance 222 on the rear side are

25   provided a plurality of pixel electrodes 224 provided

in a matrix form in a row direction and a column

direction, a plurality of TFTs 230 electrically

connected with the plurality of pixel electrodes 224, and scanning wirings 225 and signal wirings 226 which are electrically connected with the plurality of TFTs 230.

The scanning wirings 225 are provided along the row direction of the pixel electrodes 224. One end of each of the scanning wirings 225 is connected with each of a plurality of scanning wiring terminals (not shown) provided at an edge portion of the rear transparent base substance 222 on one side. A plurality of scanning wiring terminals are respectively connected with a scanning line drive circuit 241.

On the other hand, the signal wirings 226 are provided along the column direction of the pixel electrodes 24. One end of each of these signal wirings 226 is connected with each of a plurality of signal wiring 226 terminals (not shown) provided at a one end edge portion of the rear transparent base substance 222. The plurality of signal wiring 226 terminals are respectively connected with a signal line drive circuit 242. The scanning line drive circuit 241 and the signal line drive circuit 242 are respectively connected with a liquid crystal controller 243. The liquid crystal controller 243 receives an image signal and a synchronization signal supplied from, e.g., the outside, and generates a pixel picture signal Vpix, a vertical scanning control signal YCT and a horizontal

scanning control signal XCT.

One film-like transparent opposed electrode 227 which is opposed to the plurality of pixel electrodes 224 is provided on an inner surface of the transparent base substance 221 on a front side which is the other transparent base substance. Furthermore, on the inner surface of the transparent base substance 221 on the front side may be provided a color filter according to a plurality of pixel portions at which the plurality of pixel electrodes 224 are opposed to the opposed electrode 227, and a light shielding film in accordance with each area between the pixel portions.

A non-illustrated deflecting plate is provided on the outer side of the pair of transparent base substances 221 and 222. Moreover, in the transmission type liquid crystal display 220, a non-illustrated surface light source is provided on the rear side of the rear transparent base substance 222. It is to be noted that the liquid crystal display 220 may be of a reflection type or a semi-transmission reflection type.

As described above, in the crystallization apparatus and the crystallization method according to the present invention, the phase modulation element has a phase distribution based on a phase modulation unit which is optically smaller than a radius of a point spread distribution range R of the image formation optical system. Therefore, by appropriately changing

a combination of a plurality of unit vectors in a unit range optically corresponding to the point spread distribution range R of the image formation optical system, a light intensity distribution to be formed can be analytically controlled in accordance with a simple calculation. As a result, in the present invention, based on a light intensity distribution with, e.g., a concave pattern that a light intensity is minimum at the center and the light intensity is increased toward the periphery, the sufficient lateral growth of a crystal from a crystal nucleus can be realized, and a crystallized semiconductor film with a large particle size can be generated.

For example, there is provided a crystallization apparatus comprising: a phase modulation element; an illumination system used to illuminate the phase modulation element; an image formation optical system arranged in a light path between the phase modulation element and a polycrystal semiconductor film or an amorphous semiconductor film, wherein the phase modulation element has a phase distribution based on a phase modulation unit which is optically smaller than a radius of a point spread distribution range of the image formation optical system, and a crystallized semiconductor film is generated by irradiating the polycrystal semiconductor film or the amorphous semiconductor film with light beams having

a predetermined light intensity distribution. In this
structure, the phase modulation element has the phase
distribution based on the phase modulation unit which
is optically smaller than the radius of the point

5   spread distribution range of the image formation
optical system. Therefore, by appropriately changing
a combination of a plurality of unit vectors in a unit
range optically corresponding to the point spread
distribution range of the image formation optical

10   system, a light intensity distribution to be formed can
be analytically controlled in accordance a simple
calculation. A crystallized semiconductor film with
a large particle size can be generated by causing
a lateral growth of a crystal from a crystal nucleus

15   based on a light intensity distribution with, e.g.,
a concave pattern that a light intensity is minimum at
the center and the light intensity is increased toward
the periphery.

Moreover, according to the present invention,

20   there is provided an apparatus comprising: a phase
modulation element; an illumination system used
to illuminate the phase modulation element; and
an image formation optical system arranged in a light
path between the phase modulation element and

25   a predetermined surface, wherein the phase modulation
element has a phase distribution based on a phase
modulation unit which is optically smaller than

a radius of a point spread distribution range of the image formation optical system, and a predetermined light intensity distribution is formed on the predetermined surface. In this case, the light

5   intensity distribution formed on the predetermined surface can be likewise analytically controlled in accordance with a simple calculation in an appropriate apparatus other than the crystallization apparatus.

That is, the phase modulation element has a phase

10   distribution that area shares of a first area having a first phase value and a second area having a second phase value vary depending on each position. In this case, it is preferable that the phase modulation element has a plurality of cells each of which is

15   optically smaller than the radius of the point spread distribution range of the image formation optical system and area shares of the first area and the second area in each cell vary in accordance with each cell. Alternatively, it is preferable that the phase

20   modulation element has a plurality of pixels each of which is optically smaller than the radius of the point spread distribution range of the image formation optical system, each pixel has a fixed value and the number of pixels having the same phase value per unit

25   range optically corresponding to the point spread distribution range vary in accordance with each unit range. Alternatively, it is preferable that the phase

modulation element has a plurality of stripe-like areas
each having a width optically smaller than the radius
of the point spread distribution range of the image
formation optical system, each stripe-like area has
a fixed phase value, and a width of each stripe-like
area varies along a longitudinal direction.
Alternatively, it is preferable that the phase
modulation element has a line-and-space pattern having
an optically smaller width than the radius of the point
spread distribution range of the image formation
optical system, each line portion has the first phase
value, each space portion has the second phase value
and a ratio of a width of the line portion and a width
of the space portion which are adjacent to each other
varies along a widthwise direction. Additionally, the
phase modulation element has a cyclic divided area
structure, each divided area has a fixed phase value,
and the phase modulation element has a phase
distribution that the phase value varies in accordance
with each divided area. In this case, it is preferable
that the phase modulation element has a plurality of
pixels each of which is optically smaller than the
radius of the point spread distribution range of the
image formation optical system, each pixel has a fixed
phase value, and the phase value varies in accordance
with each pixel. Alternatively, it is preferable that
the phase modulation element has a line-and-space

pattern whose width is optically smaller than the
radius of the point spread distribution range of the
image formation optical system and the phase value
varies in accordance with each line portion. Further,
the phase modulation element has a first stripe-like
area which has a first phase distribution and extends
in a direction along which the phase varies and
a second stripe-like area which has a second phase
distribution and extends in a direction along which the
phase varies, the first stripe-like area and the second
stripe-like area are adjacent to each other with
a border line in the direction along which the phase
varies therebetween, and an average phase value on the
first stripe-like area side is substantially different
from an average phase value on the second stripe-like
area side in a local area on the border line.

In this case, it is preferable that the first
stripe-like area and the second stripe-like area are
configured to have substantially the same light
intensity distributions formed in accordance therewith,
an average phase value on the first stripe-like area
side is substantially different from an average phase
value on the second stripe-like area side in a first
local area on the border line corresponding to a part
with a small intensity in the light intensity
distribution, and the average phase value on the first
stripe-like area side is substantially equal to the

average phase value on the second stripe-like area side
in a second local area on the border line corresponding
to a part with a large intensity in the light intensity
distribution. Furthermore, it is preferable that the

5 first stripe-like area and the second stripe-like area
has a line-and-space pattern whose width is optically
smaller than the radius of the point spread
distribution range of the image formation optical
system, each line portion has the first phase value,

10 each space portion has the second phase value, and
a ratio in width of the line portion and the space
portion which are adjacent to each other varies along
a widthwise direction. Alternatively, it is preferable
that the first stripe-like area and the second stripe-

15 like area has a line-and-space pattern whose width is
optically smaller than the radius of the point spread
distribution range of the image formation optical
system, and the phase value varies in accordance with
each line portion. Moreover, the phase modulation

20 element comprises isolated areas each of which is
optically smaller than the radius of the point spread
distribution range of the image formation optical
system and has a phase value substantially different
from that of the periphery in accordance with parts

25 with a small light intensity in a light intensity
distribution to be formed. Additionally, in the first
or second embodiment, it is preferable that the

predetermined light intensity distribution has a light
intensity distribution with a concave pattern that the
light intensity is increased from a central area having
a first intensity toward the periphery. In this case,
it is preferable that the light intensity distribution
with the concave pattern has a distribution that the
light intensity is one-dimensionally increased from the
central area toward the periphery. Further, it is
preferable that the predetermined light intensity
distribution has a light intensity distribution with
an inverse peak pattern that the light intensity is
suddenly increased from a second central area having
a second light intensity substantially smaller than the
first light intensity toward the periphery in the
vicinity of the central area of the light intensity
distribution with the concave pattern.

Furthermore, according to the present invention,
there is provided a crystallization method comprising:
illuminating a phase modulation element having a phase
distribution based on a phase modulation unit optically
smaller than a radius of a point spread distribution
range of an image formation optical system; and
irradiating a polycrystal semiconductor film or
an amorphous semiconductor film with light beams having
a predetermined light intensity distribution through
the image formation optical system arranged in a light
path between the phase modulation element and the

polycrystal semiconductor film or the amorphous semiconductor film, thereby forming a crystallized semiconductor film. In this case, a light intensity distribution to be formed can be analytically controlled in accordance with a simple calculation like the case of the crystallization apparatus. As a result, a crystallized semiconductor film with a large particle size can be generated by causing a lateral growth of a crystal from a crystal nucleus based on a light intensity distribution with, e.g., a desired concave pattern suitable for crystallization.

Moreover, according to the present invention, there is provided a method comprising: illuminating a phase modulation element having a phase distribution based on a phase modulation unit optically smaller than a radius of a point spread distribution range of an image formation optical system; and forming a predetermined light intensity distribution on a predetermined surface through the image formation optical system arranged in a light path between the phase modulation element and the predetermined surface. In this case, the light intensity distribution formed on the predetermined surface can be also analytically controlled in accordance with a simple calculation in any appropriate method other than the crystallization method.

Additionally, according to the present invention,

there is provided a phase modulation element having
a phase distribution based on a phase modulation unit
with a predetermined size, the phase modulation element
having a phase distribution that area shares of a first
area having a first phase value and a second area
having a second phase value vary in accordance with
each position. A light intensity distribution with
a desired concave pattern suitable for crystallization
can be formed by applying this phase modulation element
to, e.g., a crystallization apparatus. As a result,
a crystallized semiconductor film with a large particle
size can be generated by causing a lateral growth of
a crystal from a crystal nucleus based on the light
intensity distribution with the desired concave
pattern.

Further, it is preferable that the present
invention has a plurality of cells and area shares of
the first area and the second area in each cell vary in
accordance with each cell. Alternatively, it is
preferable that the present invention has a plurality
of pixels, each pixel has a fixed phase value, and the
number of pixels having the same phase value per unit
range optically corresponding to the point spread
distribution range varies in accordance with each unit
range. Alternatively, it is preferable that the
present invention has a plurality of stripe-like areas,
each stripe-like area has a fixed phase value, and

a width of each stripe-like area varies along
a longitudinal direction. Alternatively, it is
preferable that the present invention has a line-and-
space pattern, each line portion has the first phase

5   value, each space portion has the second phase value
and a ratio in width of the line portion and the space
portion which are adjacent to each other varies along
a widthwise direction.

Furthermore, according to the present invention,

10   there is provided a phase modulation element having
a phase distribution based on a phase modulation unit
with a predetermined size, wherein the phase modulation
element has a cyclic divided area structure, each
divided area has a fixed phase value, and the phase

15   modulation element has a phase distribution that the
phase value varies in accordance with each divided
area. In this case, a light intensity distribution
with a desired concave pattern suitable for
crystallization can be formed by applying the phase

20   modulation element to, e.g., a crystallization
apparatus, and a crystallized semiconductor film with
a large particle size can be generated by causing
a lateral growth of a crystal from a crystal nucleus.

Moreover, it is preferable that the present

25   invention has a plurality of pixels, each pixel has
a fixed phase value and the phase value varies in
accordance with each pixel. Alternatively, it is

preferable that the present invention has a line-and-space pattern and a phase value varies in accordance with each line portion.

Additionally, according to the present invention, there is provided a phase modulation element having a phase distribution based on a phase modulation unit with a predetermined size, wherein the phase modulation element has a first stripe-like area which has a first phase distribution and extends in a direction along which a phase varies and a second stripe-like area which has a second phase distribution and extends in a direction along which a phase varies, the first stripe-like area and the second stripe-like area are adjacent to each other with a border line parallel with the direction along which the phase varies therebetween, and an average phase value on the first stripe-like area side is substantially different from an average phase value on the second stripe-like area side in a local area on the border line. In this case, a light intensity distribution with both a desired concave pattern suitable for crystallization and an inverse peak pattern can be formed by applying the phase modulation element to, e.g., a crystallization apparatus, and a crystallized semiconductor film having a large particle size can be generated by causing a lateral growth of a crystal from a crystal nucleus.

Further, the first stripe-like area and the second

stripe-like area are configured to have substantially
the same light intensity distributions which are formed
in accordance therewith, an average phase value on the
first stripe-like area side is substantially different

5   from an average phase value on the second stripe-like
area side in a first local area on the border line
corresponding to a part where a light intensity in the
light intensity distribution is small, and the average
phase value on the first stripe-like area side is

10   substantially equal to the average phase value on the
second stripe-like area side in a second local area on
the border line corresponding to a part where a light
intensity in the light intensity distribution is large.
Furthermore, it is preferable that the first stripe-

15   like area and the second stripe-like area have
a line-and-space pattern, each line portion has a first
phase value, each space portion has a second phase
value, and a ratio in width of the line portion and the
space portion which are adjacent to each other varies

20   in a widthwise direction. Alternatively, it is
preferable that the first stripe-like area and the
second stripe-like area have a line-and-space pattern
and a phase value varies in accordance with each line
portion.

25   It is to be noted that a processed film, i.e.,
a base substance manufactured by using the phase
modulation element according to any of the embodiments

of the present invention has a crystal caused to grow
to a predetermined size in the lateral direction from
a crystal nucleus, and hence an electronic device
configured by using that base substance demonstrates
excellent semiconductor characteristics. Moreover,
a display apparatus which stably operates can be
obtained by using the same base substance in, e.g.,
a liquid crystal display panel.